RoboCup2005

Rescue Robot League Competition

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www.robocup2005.org

RoboCupRescue - Robot League Team Sharif CEDRA Rescue Robot (Iran)

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Abstract. In this paper we try to explain our preparations for RoboCup 2005 until now. We also demonstrate our future plans. General issues regarding the robot's mechanical part, the control box on it, the control station and the way they function together is discussed. Also the basics of our policy in Map Generation and Localization are illustrated; this includes the software and hardware that we use in each. Finally the overall cost of the system is estimated.

1. Team Members and Their Contributions

• Ali Meghdari	Supervisor
• Seyed Hamidreza Alemohammad	General Director
• Mohammad Moeeni Aghkariz	Electrical Group Leader Operator
• Hodjat Pendar	Mechanical Group Leader Mechanical Design and Analysis
• Yasin Khatami	Map Generation and Localization
• Elyas Khameneh	Robot OS and Software Development GUI and Control Station
• Reza Haji Aghaee Khiabani	Manufacturing and Part supplement
• Mohsen Reza Soltani	Mechanical Design
• Hossein Khasteh	Digital Interfacing RF Communication
• Navid Rafatian	Dynamic Analysis System Modeling and Simulation
• Hoda Sadeghian	Mechanical Design

- Sponsors — Industrial Development and Renovation Organization of Iran (www.idro.org)
Center of Excellence in Design, Robotic and Automation (http://sharif.edu/~cedra)

2. Operator Station Set-up and Break-Down (10 minutes)

While a rescue team is preparing to do a mission over disaster area, great mass of equipments and complexity of their installation will decrease time and energy efficiency of the operation. A suitcase-shaped package which is called control station has been designed and is under development to avoid complex setup process. It will contain all necessary communication, tele-operation, data processing and user interfacing tools inside. Also internal UPS would help to operate in electricity blackouts. The total setup time of this system is estimated bellow 2 minutes (one minute of installation and an extra one for initialization of devices). It is light enough to be carried over mid distances. In addition to that station, an extra hand held tele-operating device has been developed; it will help to navigate the robot while walking.

Fig. 1. 3D Artwork of designed control station. Left LCD displays GUI while the right LCD shows a large camera view.

3. Communications

Since 802.11a wireless LAN products are very easy to use and have a large bandwidth, we prefer to use them. LAN products seem to be very suitable as communication links for transmitting commands from control station to robot and receiving data from onboard sensors.

We also have chosen Maxstream® Radio Modems which use 900 MHz ISM band and frequency hopping spread spectrum with 7 hopping patterns. Thus, 7 separate networks can work very close to each other. Effective Radiated Power (ERP) in output is about 140mW and bit rate on air is 19200 bps (Figure 2).

Fig. 2.a. Maxstream® Standalone Radio Modem. **b.** Audio/Video sender.

An analog Audio/Video sender in 1.2- 1.4GHz with 500mW ERP in output is used for audio and video streaming. Operator can select one of the 5 cameras on robot for watching the environment with an embedded multi-channel analog switch (Figure 2).

Frequencies that we will use in the competition are listed in Table 1.

Table 1. Frequencies that we will use in Robocup Competitions.

Rescue Robot League		
CEDRA (Iran)		
Frequency	**Channel/Band**	**Power (mW)**
5.0 GHz - 802.11a	Any world channel assigned by Robocup Chair	50
1.2 GHz	-	500
900 MHz	-	140

4. Control Method and Human-Robot Interface

The human-robot interface of control station is composed from two main sections: First, Graphical User Interface (GUI) which is used for multi feature control of robots, and the second, map generation software.

In the GUI, operator uses a joystick (Wingman Attack II from Logitech) to control and navigate the robot and also set the PTZ (Pan-Tit-Zoom) camera (EVI-D70 from Sony®) view. The operator transmits the appropriate commands to the robot to find the correct way and detect the victims. Also the control station automatically processes incoming data packets and monitors the results of them.

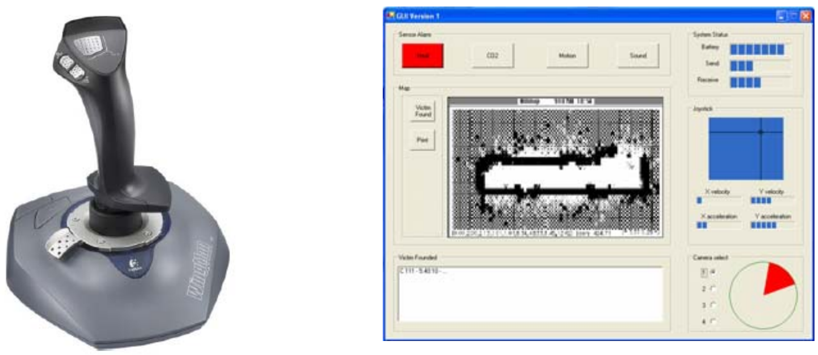

Fig. 3. a. Wingman Attack II **b.** Primary version of GUI, it monitors robot's status, generated map, measurement of sensors, camera filed of view, joystick position, and RF connection quality.

Data packets contain measurements of each sensor such as Thermometer or CO2 detector, the result of local processed data, such as orientation and position of robot and also raw readings of Sonars. When a sign of life is detected, an alert will aware the operator. In general, many issues can be considered in this unit.

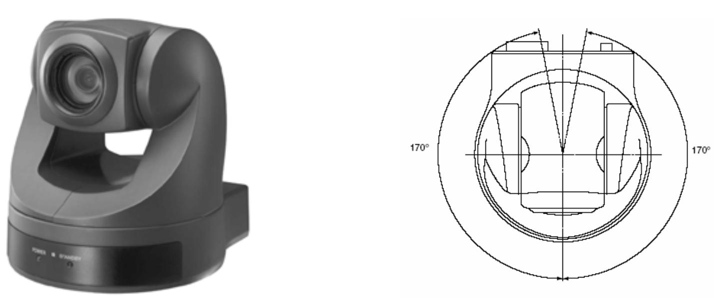

Fig. 4. Sony EVI-D70 PTZ robotic camera gives a 340° field of view with maximum pan speed

of 100°/S and 18x optical zoom.

Map generation software receives the positional data from the robot. Indeed, robot can detect all stuff in the disaster area with rangefinder sensors (for example walls, seats, etc.) and sends their position to control station. Map generation software plots the map of that area and shows it on the screen. Whenever a victim is detected, operator will zoom the PTZ camera on him/her and press *New Victim* key on the station. Then, position of the victim in the map will be marked and in consequence a dialog box will be opened to edit records on victim. The operator can print out both map and victim datasheet for rescue team.

5. Map generation/printing

Map generation is a dynamic process that needs implementing real-time data of range finding sensors. After studying different sensor technologies, we decided to use Ultrasonic rangers for this purpose (SRF08 from Devantech®). The task of map generation has been divided into two parts: Simulation and Real world data manipulation. In order to analyze different algorithms for map generation in various kinds of environments, a simulation program is developed. In this program the environment and Sonars are simulated and the raw data of sensors is fed to the desired algorithm which filters them to a map. The main challenge of the map generating algorithm is to handle great noisy and faulty sonar readings and also their conical view (See Figure 5.a).

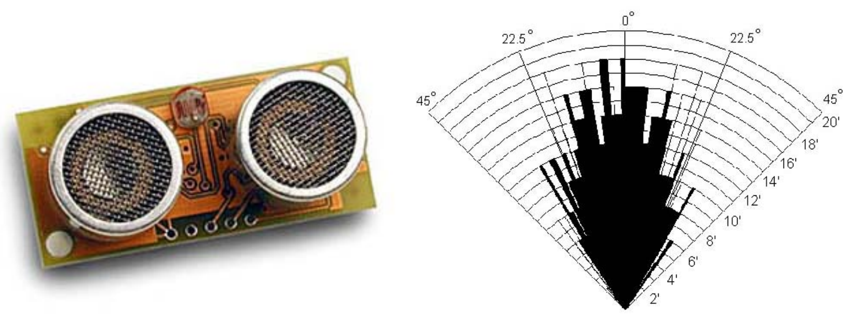

Fig. 5. a. Devantech's SRF08 Sonar and **b.** its conical view 2D pattern.

Many different mapping algorithms has been studied, but now we are focusing on occupancy grid based methods, such as Histogramic In Motion Mapping (HIMM) [1]. In these methods, the map is broken into cells, and the cells are updated with real-time readings of range finders. Thus, a certainty number is assigned to each cell. More occupancy number of the cell means more probability of being occupied by a real object (See Figure 6).

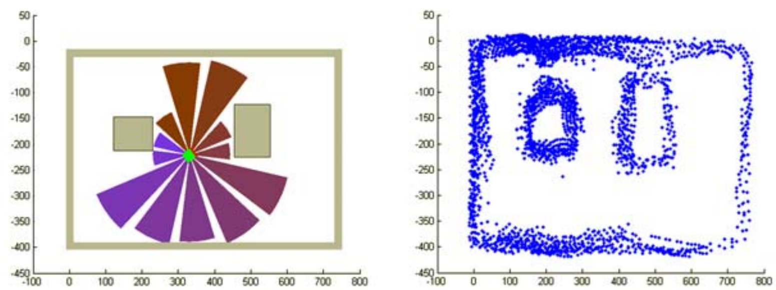

Fig. 6. a. Our developed real-world simulator helps us to study different environment configurations. **b.** Raw data of sonar measurements.

The HIMM method is a real time enhancement of the certainty grids. In this method certainty numbers are assigned to axes of conical view of sensors which makes this method a real time one and reduces processing load. If a sensor detects an object in a cell its certainty number will increase. In real world, the probability of a cell for being occupied has a Gaussian function so a certainty should be assigned to each cell in the conical view of ultrasonic sensors.

HIMM method uses a GRO (Growth Rate Operator) to increment a cell faster when the immediate neighbors of the cell hold high to intensify real objects. This function distinguishes real obstacles from faulty measurements as well.

6. Sensors for Navigation and Localization

According to the fact that a single dead-reckoning reference is insufficient for robot positioning, we've used two main devices for measuring robot's position and orientation:

1- Wheel Odometry.

2- Inertial Measurement Unit (IMU).

For better state estimation, we combine both encoders and INS (Inertial Navigation System) data by using *Kalman filter*. Kalman filter is a set of mathematical equations that provides an efficient (recursive) computational solution of the least-squares method. The filter is very powerful in several aspects: it supports estimations of past, present, and even future states, further more it can work when the precise nature of the modeled system is not known [2].

Kalman filter estimates the position by using a form of feedback control; the filter estimates the position state at some time and then obtains feedback in the form of (noisy) sensor measurements. Thus, the equations for the Kalman filter fall into two groups: *time update* equations and *measurement update* equations. The time update equations are responsible for projecting the current position state and error covariance estimates forward (in time) to obtain the *a priori* estimates for the next time step. The measurement update equations are responsible for the feedback.

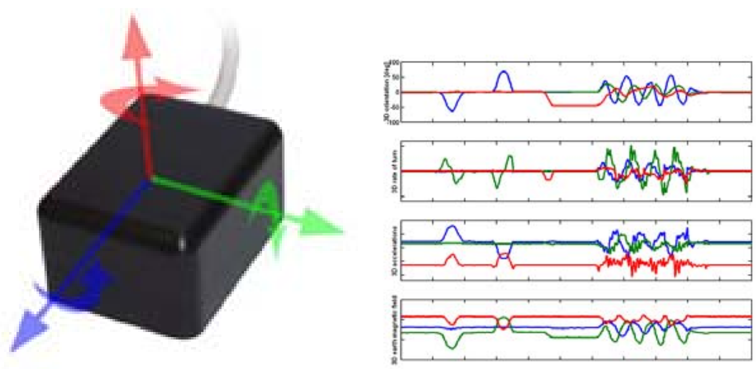

Fig. 7. a. An IMU provides 3DOF rate of turns and 3DOF rate of displacements in space by means of MEMS accelerometers and gyros.

The time update equations can also be thought of as *predictor* equations, while the measurement update equations can be thought of as *corrector* equations. Indeed the final estimation algorithm resembles a *predictor-corrector* algorithm for solving numerical problems as shown below in Figure 8.

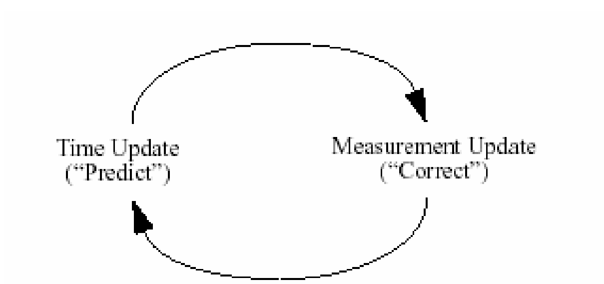

Fig. 8. The ongoing discrete Kalman filter cycle. The *time update* projects the current state estimate ahead in time. The *measurement update* adjusts the projected estimate by an actual measurement at that time.

After each time and measurement update pair, the process is repeated with the previous *a posteriori* estimates used to project or predict the new *a priori* estimates. This recursive nature is one of the very appealing features of the Kalman filter.

The specific equations for the time and measurement updates are shortly presented in Figure 9.

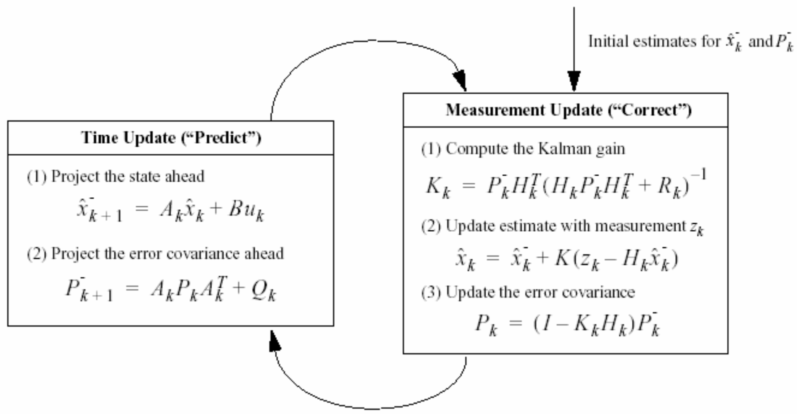

Fig. 9. A complete schematic of the operation of the Kalman filter

NASA FIDO Rover Localization method is also used in our method to get better results for both position and orientation estimation [3]. This method is a two-tire state estimation approach for NASA FIDO Rover that utilizes wheel Odometry and inertial measurement sensors. The state estimation approach makes use of the linear Kalman filter to estimate the rate gyro bias terms associated with the inertial measurement sensors and then uses these estimated rate gyro bias terms to compute the attitude of the rover during a traverse. The estimated attitude terms are then combined with the wheel Odometry to determine the rover's position and attitude through an extended Kalman filter approach.

Up to now we have examined some Kalman filter algorithms to apply this filter to our sensors data. Bellow is the simplest linear Kalman filter code (MATLAB) to estimate a constant value with combined white noise.

```
x=1:31;
xm=x;
p=x;
p_=x;
r=0.01;
z=randn(1,31);
z=z-mean(z);
z=z/(var(z)^0.5)
z=z*r^0.5
z=z+0.4
```

```
q=1e-5;
p_(1)=1;
xm(1)=0;
for k=1:30,
kk(k)=p_(k)/(p_(k)+r);
x(k)=xm(k)+kk(k)*(z(k)-xm(k))
p(k)=(1-kk(k))*p_(k);
xm(k+1)=x(k)
p_(k+1)=p(k)+q;
end
plot(1:30,x(1:30),'b');
%plot(1:30,xm(1:30),'r');
hold on;
plot(1:30,z(1:30),'+r');
```

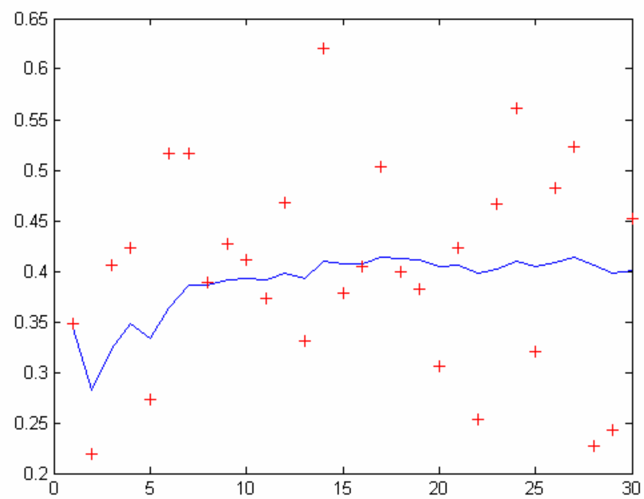

Fig. 10. The Output of Kalman Filter sample code in MATLAB.

7. Sensors for Victim Identification

One of the major tasks of an operational rescue robot is helping human rescuers by identifying victim's status, and this is done by gathering some information about his/her consciousness (moving, screaming, etc.), body heat and also breathing (CO2 emission). Since usual rescue robots don't have a precise control on their movements, it is better to do these measurements by non-contact means to avoid hurting victims.

Sound and video of the scene are sent to the station so that operator can easily detect any life sign there. Also, a non-contact infrared pyrometer has been used (IN5 from Impac®) to detect victim's body heat. This digital RS-232 sensor measures temperatures in maximum distance of 4 meters with special optics.

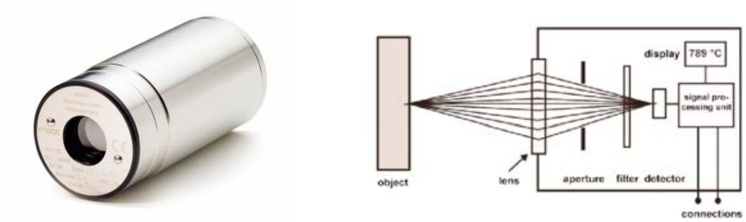

Fig. 11. a. IMPAC® Non-Contact digital pyrometer and **b.** its functional block diagram.

Most of CO2 detectors use famous NDIR (Non Dispersive Infra Red) technology to measure part per millions (PPM) of Carbon Dioxide in the air. The usual amount of CO2 in a room is about 360PPM while any CO2 gas leakage may increases it to thousands of PPM (above 10000 PPM is poisoning for human). The normal amount of CO2 in exhaled breath of human is about 40000 PPM. Most of commercial NDIR CO2 detectors measure the range of 100 to 2000 PPM. We are still looking for a good module, but OEM detectors from Edinburgh® seem great.

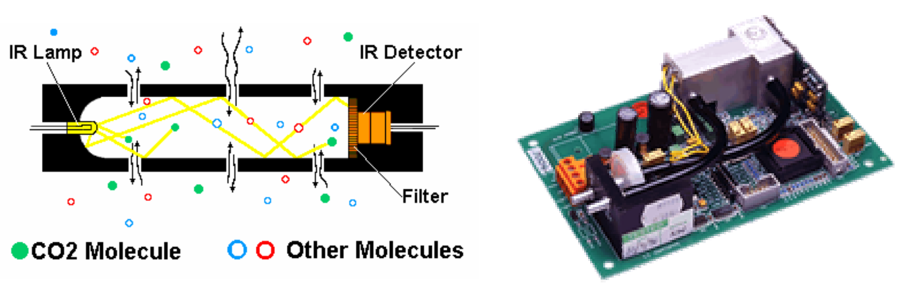

Fig. 12. a. NDIR CO2 Detectors basic structure **b.** Edinburgh's Gascard©.

8. Robot Locomotion

We intend to use two different robots in the competition. One is a modified shrimp rover and the other is a hybrid tracked robot. The shrimp rover robot is the modified version of *CEDRA-I Shrimp Rover* (2nd place in Rescue Robocup 2003). The Two versions of shrimp rovers are depicted in Figure 13.

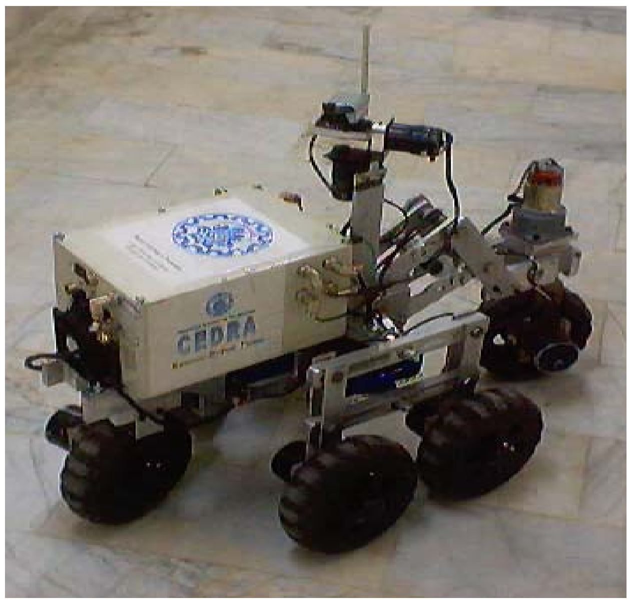

Fig. 13. a. *CEDRA_I Shrimp Rover*

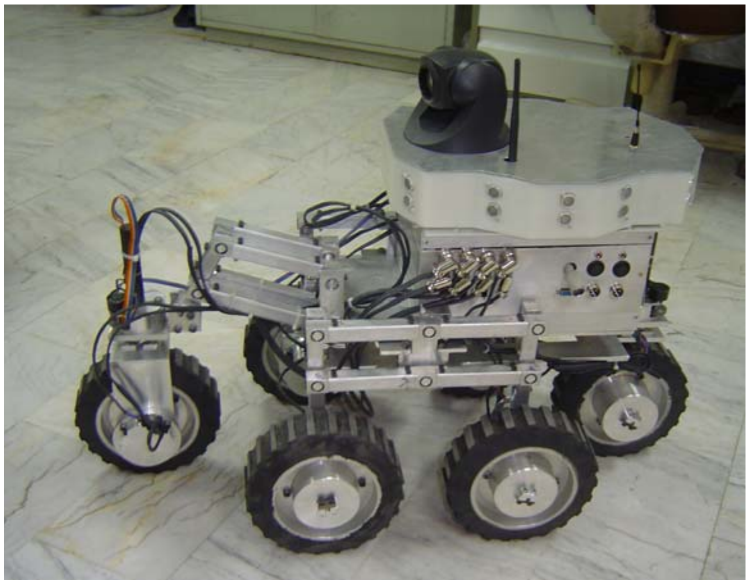

Fig. 13. b. Revised shrimp rover

The hybrid tracked robot is a new robot and has a flexible mechanism and is capable of adapting itself to the environment; it can switch between wheeled and tracked modes (Figure 14).

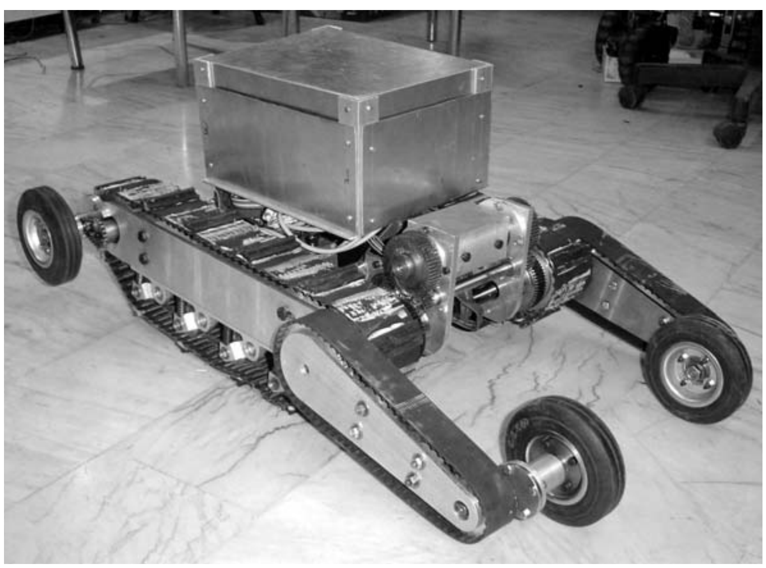

Fig. 14. CEDRA hybrid tacked robot

This couple (shrimp rover and hybrid tracked robot) work like a team. They complete each others' capabilities. A more through explanation of each robot, their specifications and their potential use will follow.

8.1 Shrimp Rover

Shrimp Rover has six wheels that operate separately; back and front wheels and four side wheels that are mounted in parallel bogies system; the front wheel is placed on a front-fork mechanism (see Figure 15). Special design, flexible elbows, and a spring fitted in the front elbow that works as a pushing force, together make it possible for robot to adjust rough areas and obstacles such that all six wheels touch the ground simultaneously as shown in Figure 16 [4][5].

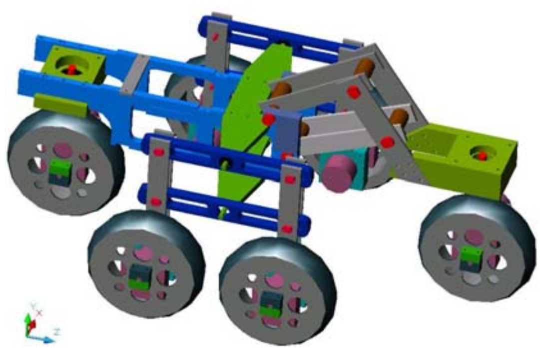

Fig. 15. The CAD model of Shrimp Rover.

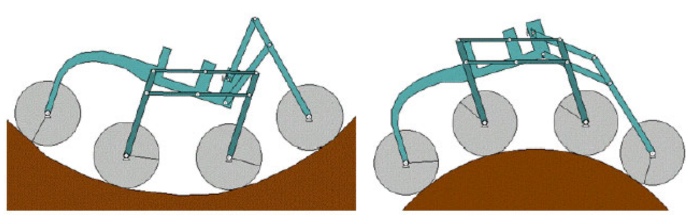

Fig. 16. The robot flexibility in Convex/Concave environment.

- Front Fork

The robot’s front fork has three roles as described below (see Figure 17):

1-The spring makes it possible for wheels to touch the ground all the time.

2-When the robot encounters an obstacle; the horizontal force acting on the front wheel creates a torque around the instantaneous rotating center of the front wheel. The four bar mechanism design in the front wheel, shows that the instant center is set under the horizontal line, and therefore causes the wheel to move up accordingly [4][5].

3-When the front wheel is going up, spring is compressed and energy is stored in the front wheel. Although, other wheels are not in a good condition during climbing and they don't touch the ground completely, but this stored energy helps them to move up easier. Figure 18 shows the performance of the front fork in passing obstacles.

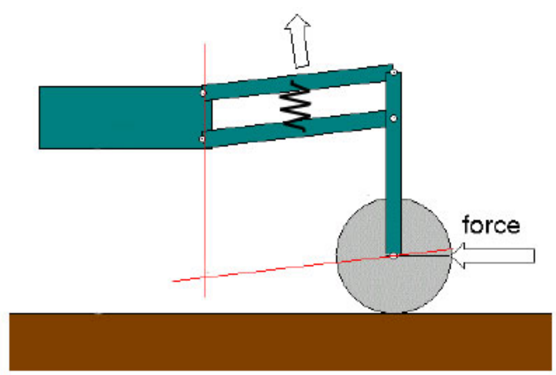

Fig. 17. The front wheel.

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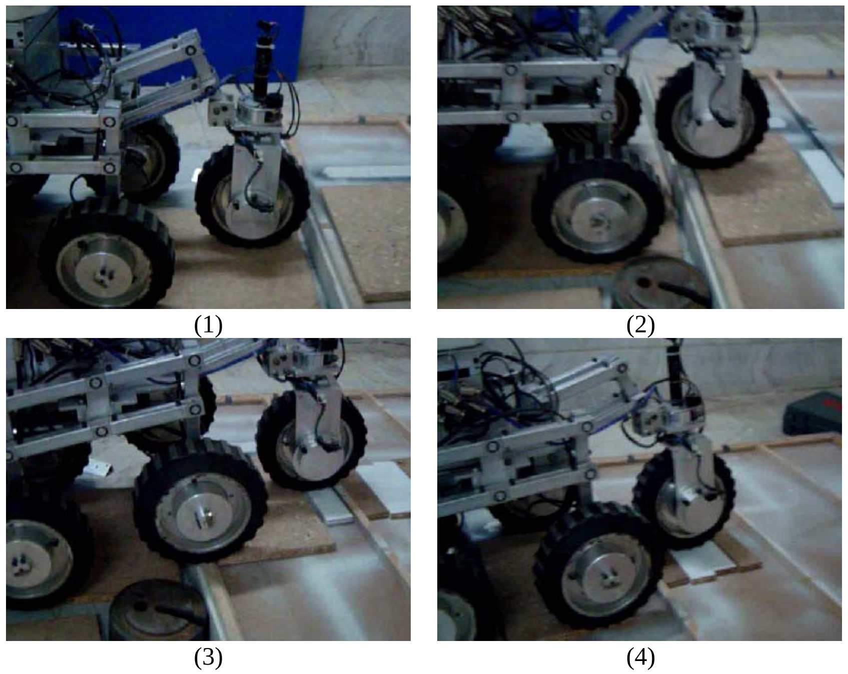

Fig.18. Shrimp Rover passes an obstacle.

- Bogies

Since parallel bogies pass the obstacles easier than classical bogies (although both have similarities in kinematics and in kinetics), they are used in this design (Figure 19).

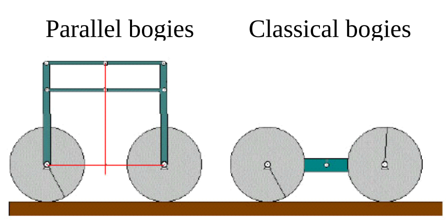

Fig. 19. The bogies.

- Robot Seesaw System

The wheels are coupled so that the force distribution be the best possible. The spring and dimensions of the robot are designed in a way that when it is standing on a planar surface, forces acted on all six wheels are the same (Figure 20).

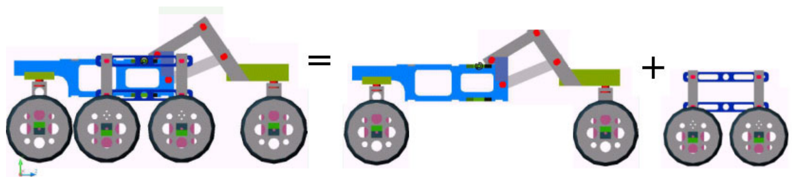

Fig. 20. The seesaw mechanism in the robot.

- Steering

In this robot, each of six wheels has their own drivers, the front and back wheels have angle adjusting and controlling system. Also the steering causes speed difference in side wheels and adjust the angle of front and back wheels. This steering strategy increases the accuracy of robot maneuvers, and the robot can also turn in its place with minimum slip (Figure 21) [4][5].

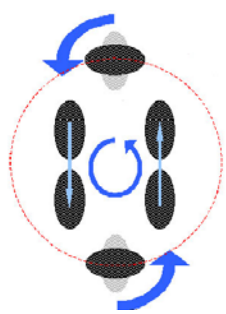

Fig. 21. Turning of robot.

- Shrimp Rover Modifications

In order to improve the performance of the first version, some modifications have been done which resulted in the new version of the shrimp rover. In this section the modifications that have been done on the first version of shrimp rover are introduced.

- **Improving the operation of wheels:**

In this project we considered the frictional characteristics of the wheels as well as their dimensions. In this regard material and manufacturing issues were studied to get relevant friction coefficient. It is important to have enough frictional force to climb steeps. Also the wheels should be as light as possible with enough rigidity to carry the robot.

- **Increasing speed:**
  The robot should be able to move fast through steep and rough planes or on the surface. This is a challenge between friction, weight, dimensions and motor power. A dynamic analysis was performed in order to determine the best dimensions. In this regard the optimum speed was determined.

- **Ability to climb sharp steeps and steps:**
  The mechanism and dimensions of links and also motors were designed and optimized in such a way to have maximum performance during robot operation. The robot is able to climb stairs of different size and also sharp steeps [4].

- **Improving the placement of different parts:**
  We placed parts in a better configuration to get more benefits and get more places to locate sensors and electrical elements.

- **Stability:**
  The stability of robot is an important issue that increased to get relevant conditions. This is very important when robot moves through rough planes [4].

- **Optimizing weight:**
  The weight of robot has an important effect on performance of robot and on power needed to move it. It has been optimized using light materials that have enough rigidity.

- **Dynamic Analysis (3D Modeling, Newton…)**
  Dynamic analysis was done to use its results as a tool for improvement of robot operation. Using this analysis we could optimize the dimensional parameters of robot such as length of linkages [4].

8.2 Hybrid Tracked

The urban environment poses a great challenge for autonomous mobile robots. From the mobility point of view, many man-made structures such as curb or stair are difficult for small robot to overcome. The main objective of this robot is to pass over these obstacles even in damaged environments that may be encountered in an earthquake or other natural disasters.

The Rescue Tracked Robot chassis provides a simple mechanism to climb stairs and rough obstacles. This combination creates a robot that can autonomously operate in widely varying terrain and can investigate different environments that are dangerous to human. Figure 22 shows the overall mechanical design of the vehicle.

The vehicle has two main tracks along its body. These two tracks are used for driving and steering. In the front of the vehicle, there are two auxiliary articulated arms with tracks. These arms can rotate more than 320 degrees relative to the main arm; this capability makes the robot adaptable. The vehicle uses the two arms to mount stairs and other obstacles. When the vehicle is on the stairs, the arms are straightened out to provide more stable support. Figure 23 illustrates the mechanism in which the vehicle passes an obstacle.

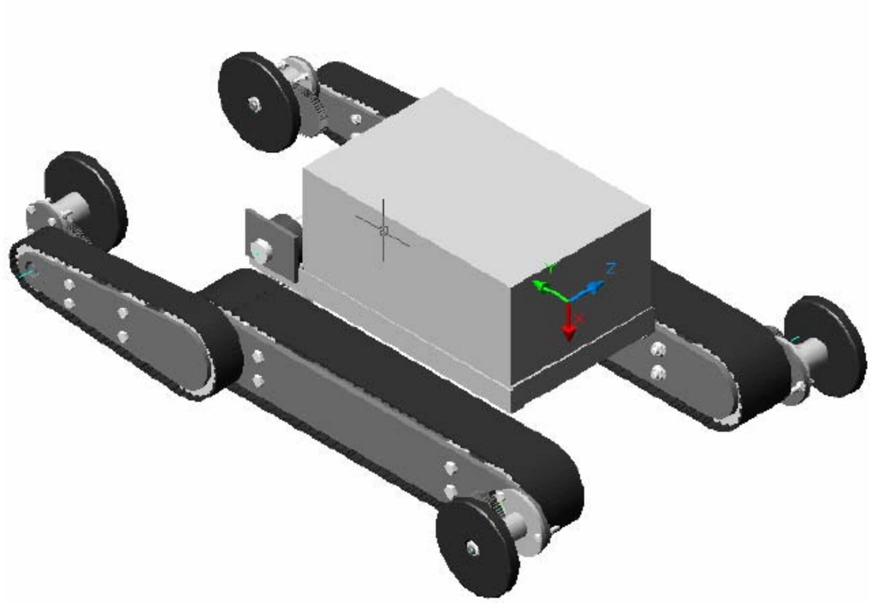

Fig. 22. Overall mechanical design of vehicle.

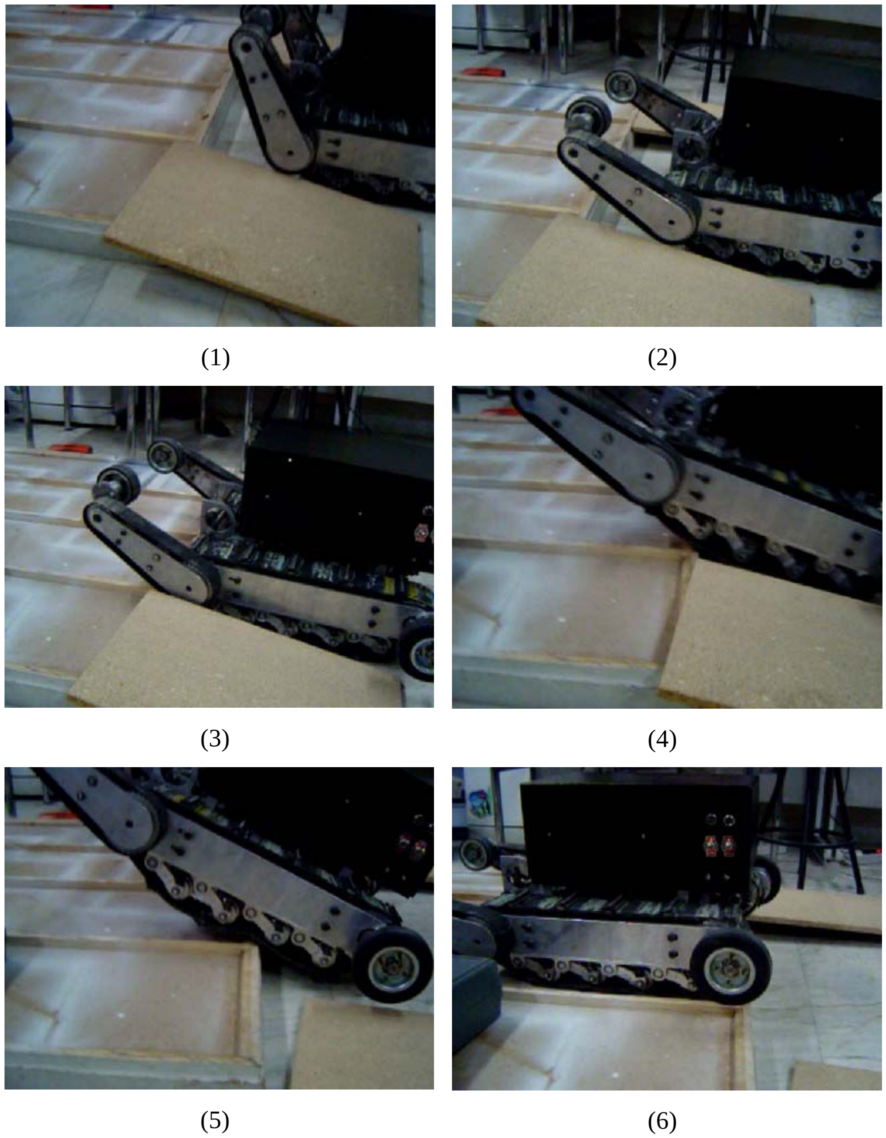

Fig. 23. Hybrid Tracked Robot passing an obstacle.

In order to enhance the capabilities of the vehicle in passing obstacles, a suspension unit has been added to tracks. The suspension consists of helical springs that are mounted within the space between tracks and the vehicle chassis. This unit make the vehicle more adaptable in passing rough terrains (Figure 24).

Fig. 24. Vehicle suspension unit.

The Rescue Tracked Robot is a hybrid vehicle that has wheels as well as tracks. The wheels are geared to rotate faster than the tracks' driving speed. When the robot is placed in "wheel mode" it can travel much faster over smooth terrains (i.e. yellow region in Robocup competitions). When the robot needs to climb stairs or travel over rough ground (i.e. orange and red regions in Robocup competitions), it will roll back into "tracked mode". Figure 25 shows the robot in "wheel mode" and "tracked mode".

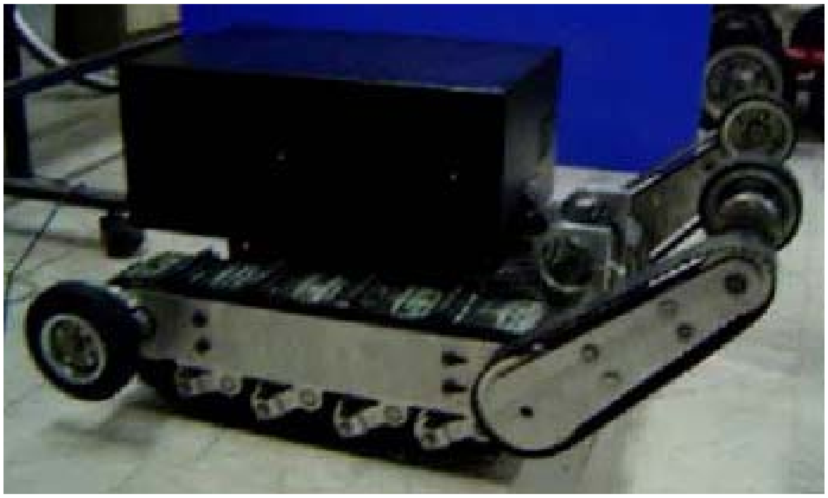

Fig. 25. a. Hybrid Tracked Robot in “tracked mode”.

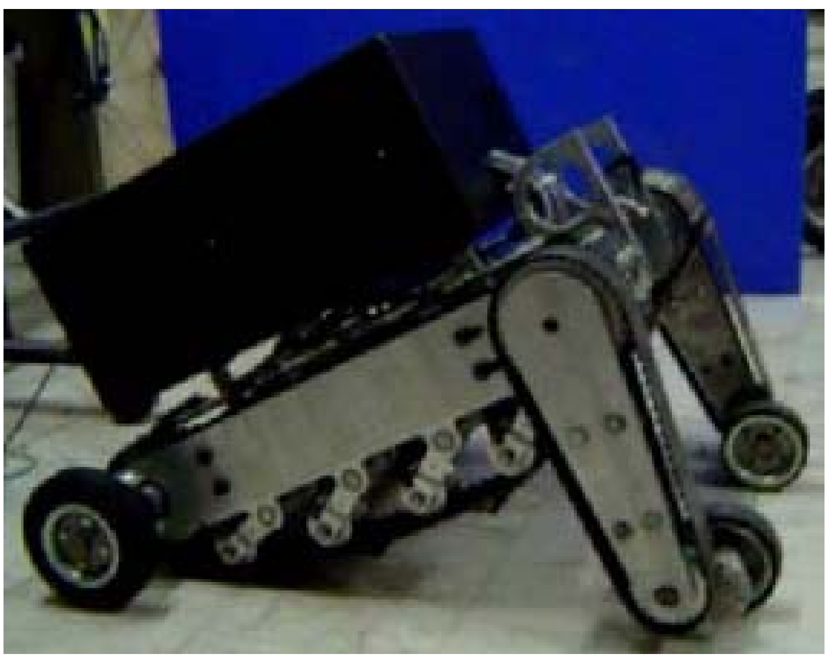

Fig. 25. b. Hybrid Tracked Robot in “wheel mode”.

The robot power is supplied by five EC motors. General motion of the robot is maintained by the movement of two main tracks. These tracks are powered by two 150 watts EC motors. The articulated arms which are used in obstacle-climbing are powered independently by two 50 watts EC motors.

As mentioned above, the robot is supported by 4 wheels in “hybrid mode”. The two front wheels, which are coupled to the auxiliary arms’ track, are powered by the mentioned 50 watts EC motors. The two rear wheels are also coupled to the main tracks that are powered by the mentioned 150 watts EC motors.

The configuration changing from “tracked mode” to “wheel mode” or vice versa is done by an innovative mechanism. A 150 watts EC motor is considered for this task. This motor is geared to articulated arms.

9. Other Mechanisms

Our mechanisms are restricted to wheeled, tracked and shrimp which are all a part of previous section.

10. Team Training for Operation (Human Factors)

The developed GUI software in the control station is completely user friendly. Hence anyone who knows how a Mouse or Joystick works can be an operator. In other words, our system doesn't need any special skills for its operator. In order to act well in real disaster situation, the operator must have a good control in his body psychological system. He or she shouldn't loose self control on front of many problems and bad situations which may occur in real disaster. On the other hand, the operator must be capable of repelling to critical events and have innovative thought for solving problems and detecting the victims.

At least 3 hours experience in working with robot is recommended, it would help the operator to handle the robot much better. Also in real disaster, it will be very helpful if operator knows a little about medicine to find the current victims status quickly.

Our team members are best adroit students from Sharif University of Technology (the best university in Iran).They are top elites students from different fields (Electrical, Mechanical and Computer engineering). We have tried to explain all of the competition rules to our members. Thus, our team members have become completely familiar with the rules from the beginning.

11. Possibility for Practical Application to Real Disaster Site

The robots are not yet tested in a real disaster area, but we believe they could be quite helpful for victim identification especially when we are dealing with a situation in which we are not sure of victim existence in a location. The rescue robot couples can easily explore the sight and report any signs of possible victims. Problems that we may encounter are mainly non-autonomous actions of robot, loss of battery, loosing wireless contact ….

12. System Cost

Our main expenses are sensors. You can find relative data in Table 2. Apart from sensors we used in our robot we had to pay a great amount of money for drive sets (i.e. motors, gear heads, drivers, and encoders). We used Maxon® Motors in our systems. They are light, powerful and exact, but quite expensive. The third main system cost is manufacturing expenses. This stands for mechanical as well as electrical parts and manufacturing and also money we used to buy standard parts (ICs, Ball bearings …). The overall project expenses are estimated in Table 3.

Table 2. The Sensors Cost

Sensor's type	Price per piece	Distributor
IMU	2100 US$	www.xsens.com
Laser Scanner	8500 US$	www.sick.de
CO2 detector	500 US$	www.edinst.com
Mini Camera	50 US$	Proline UK
EVI-D70 PTZ camera	1050 US$	www.maxxvision.com
Wingman II joystick	20 US$	www.logitech.com
Head tracker	995 US$	www.vrealities.com
Pyrometer	600 US$	www.impac.com

Table 3. System Overall Cost

Expenses	Value
Sensors	14615 US$
Drive sets	12000 US$
Manufacturing and Standard Parts	10000 US$
Others	1000 US$
Total	**37615 US$**

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